"This book provides an in-depth introduction to radio resource management (RRM) in wireless networks. Through various practical examples, it demonstrates how to model and analyze RRM problems and optimize wireless network performance. It is an outstanding textbook for graduate students and an excellent scholarly reference for engineers and researchers."

Geoffrey Li, Georgia Institute of Technology

Radio Resource Management in Wireless Networks

An Engineering Approach

Do you need to design efficient wireless communications systems? This unique text provides detailed coverage of radio resource allocation problems in wireless networks and the techniques that can be used to solve them. Covering basic principles and mathematical algorithms, with a particular focus on power control and channel allocation, you will learn how to model, analyze, and optimize the allocation of resources in both physical and data link layers for a range of different network types. Both established and emerging networks are considered, including CDMA and OFDMA wireless networks, relay-based wireless networks, and cognitive radio networks. Numerous exercises help you put knowledge into practice and provide the tools needed to address some of the current research problems in the field.

This is an essential reference whether you are a graduate student, researcher, or industry professional working in the field of wireless communication networks.

Ekram Hossain is a Professor in the Department of Electrical and Computer Engineering at the University of Manitoba, and a Fellow of the IEEE. He is the co-author or co-editor of several books, including *Wireless Device-to-Device Communications and Networks* (Cambridge, 2015) and *Smart Grid Communications and Networking* (Cambridge, 2012).

Mehdi Rasti is an Assistant Professor in the Department of Computer Engineering and Information Technology at the Amirkabir University of Technology in Iran. He previously worked at the Shiraz University of Technology (Iran) and the Wireless@KTH Royal Institute of Technology (Sweden).

Long Bao Le is an Associate Professor in the National Institute of Scientific Research (Energy, Materials, and Telecommunications) at the University of Quebec.

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EKRAM HOSSAIN
University of Manitoba

MEHDI RASTI
Amirkabir University of Technology

LONG BAO LE
University of Quebec

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Preface

Wireless communications and networking technology are advancing at a very rapid pace. Newer technologies and standards are evolving to serve the ever-increasing number of users demanding different types of mobile applications and services. Research and development activities on wireless technology constitute one of the most important segments of research and development in the telecommunications area today. Radio resources such as the radio spectrum and transmission power are the fundamental ingredients for any wireless system. Radio resource management is a fundamental problem in wireless networks. Efficient allocation and management of radio resources to serve the mobile users with different requirements is essential for practical deployment and operation of wireless communications systems and networks.

Radio resource allocation is a very broad topic that cannot be fully covered in a single book. This book with the title *Radio Resource Management in Wireless Networks: An Engineering Approach* particularly focuses on resource management issues related to power control, interference management, joint power control and cell association, channel assignment, and multiple access control in traditional as well as emerging wireless networks such as multi-tier cellular, relay-based cellular, and cognitive radio networks (CRNs). This book intends to provide background knowledge on resource allocation in wireless networks from a system-centric or engineering point of view, review the existing related literature, discuss the research challenges, present different techniques to model and analyze the resource allocation problems, and develop both centralized or distributed resource allocation algorithms. This book includes the classical as well as recently developed models and analyses for allocation of different resources (e.g., spectrum and transmission power) in cellular wireless networks. It will be useful for graduate students (M.Sc. and junior Ph.D. students) to understand different resource allocation problems and algorithms in different types of wireless networks (i.e., both infrastructure-based and infrastructure-less wireless networks). It can be used as a textbook for a graduate course on "Wireless Networks" as well as a reference book for researchers and engineers working in the area of wireless communications and networks.

Graduate students who intend to work in this area need to familiarize themselves with the basic concepts of resource management (e.g., power control, channel allocation, error control) in wireless networks and the related mathematical models. The majority of currently existing textbooks on Wireless Communications/Mobile Networks focus on the physical layer (PHY) aspects of wireless communications and do not provide an

in-depth treatment of the resource allocation as well as medium access and radio link control problems in wireless networks. This book intends to fill in this gap and cover the state-of-the-art of research and development in this area. This book can serve as a quick reference for major radio resource management issues in wireless networks as well as related mathematical models for analysis and optimization of radio resource management techniques.

The key features of this book are as follows:

- A systematic view looking at resource management problems in wireless networks that will help readers to classify and compare different types of problem formulations and extend the existing modeling approaches and solution concepts to new system models;
- A comprehensive review of the state-of-the-art research on major resource management problems (e.g., channel and power allocation, error control) in wireless networks;
- Coverage of a wide range of techniques from optimization and game theory (along with examples) for design, analysis, and optimization of resource allocation methods in wireless networks;
- Examples and practice problems (exercises) on different resource management problems;
- Outlines for the key research issues related to resource management in wireless networks.

We have organized the book into the following parts.

Part I: Basics of Wireless Networks

In Chapter 1, starting with an introduction to wireless communications (including signal characterization and modulation, radio propagation and channel models for wireless packet communications), different wireless access technologies (e.g., cellular wireless, wireless local area network [WLAN], wireless metropolitan area network [WMAN], and wireless personal area network [WPAN] technologies) are briefly reviewed. Issues related to medium access control in wireless networks are also discussed.

In Chapter 2, basics of protocol layers for data communication, categorization of different wireless networks, and the fundamentals of modeling and analysis of different physical and radio link layer techniques (including different digital transmission and smart reception techniques, multiple access, scheduling, error control, power control, cell association, handoff management and admission control methods) are discussed. Also, a high-level taxonomy of research areas related to resource management in wireless networks is presented.

Part II: Techniques for Modeling and Analysis of Radio Resource Allocation Methods in Wireless Networks

This part presents different techniques, which can be applied to model and analyze the resource allocation problems in wireless networks. In Chapter 3, optimization techniques are discussed. Major variations of optimization techniques (e.g., unconstrained

and constrained optimization, nonlinear optimization, combinatorial optimization) are presented along with several examples of their applications in modeling and analysis of radio resource management problems.

In Chapter 4, game theory techniques are discussed in the context of optimizing radio resources. The basics of different game theoretic models, namely, non-cooperative game, auction game, and coalition game models, are presented. Several examples of applications of these game models for power control, bandwidth allocation, and sharing in wireless networks are discussed.

Part III: Physical Layer Resource Allocation in Wireless Networks

This part deals with the distributed power control and user association problems in wireless networks. Chapter 5 presents the system model, notations, basic definitions, and relationships related to uplink and downlink power control in interference-limited cellular networks. Both single-cell and multi-cell scenarios are considered. This chapter provides the basics to understand the materials presented in the subsequent chapters of this part of the book.

Starting with a discussion on the motivations of power control, Chapter 6 discusses the conventional open-loop, closed-loop, and centralized power control methods. Then it discusses different existing power control algorithms for homogeneous (single-tier) wireless cellular networks. In this context, different objectives of distributed power control (e.g., aggregate transmit power, system throughput, and outage ratio) are discussed. The existing power control algorithms are compared in terms of different criteria such as fixed-point existence and uniqueness, convergence, rate of convergence, objective functions, and implementation complexity in terms of signaling overhead.

Chapter 7 deals with the joint distributed power and admission control problem in cellular networks. The existing methods for joint admission and power control are discussed, and the state-of-the-art results are summarized.

Chapter 8 deals with the joint power and admission control problem in underlay CRNs, where primary users have a higher priority than secondary users while accessing the radio spectrum. Different optimization models for this problem are introduced, the feasible interference regions for the primary users are characterized, and the existing algorithms for centralized joint power and admission control are reviewed. To this end, two algorithms are presented for joint power and admission control in CRNs.

Chapter 9 deals with the distributed cell association problem (also called the user association problem) in cellular networks. The existing methods for distributed cell association are reviewed, and the problem of distributed joint cell association and power control is studied. Also, methods for generalizing the existing distributed power control algorithms to joint power control and base station (BS) assignment algorithms are discussed.

Part IV: Link Layer Resource Allocation in Wireless Networks

Chapter 10 provides an overview of the channel allocation methods in multi-carrier (e.g., orthogonal frequency division multiple access [OFDMA]) networks. Also, some open research issues are discussed.

Chapter 11 deals with the resource allocation problem in cooperative (e.g., relay-based) networks. The fundamental aspects of cooperative protocols and resource allocation methods for single and multi-carrier relaying networks are presented.

Chapter 12 presents a survey on the channel allocation methods for wireless local area networks (WLANs). A qualitative comparison among the different methods is made and current practices in channel allocations are discussed. Several open research directions in this area also outlined.

Part V: Cross-Layer Modeling for Resource Allocation in Wireless Networks

Chapter 13 discusses important models for performance analysis and cross-layer (e.g., physical-link) design of radio link level error control methods. In particular, it covers the fundamental aspects of analysis and design of automatic repeat request (ARQ) and hybrid ARQ (HARQ) protocols considering wireless channels with different characteristics.